

ASA Satellite Missions and Key Participants

Volume VI — 1988 and 1989

53 p



(NASA-TM-109259-Vol-6) MAJOR NASA
SATELLITE MISSIONS AND KEY
PARTICIPANTS. VOLUME 6: 1988 AND
1989 (NASA) 53 p

N94-70793

Unclass

29/12 0185629

NASA

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Space Administration

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1988 Missions

2

SAN MARCO - Scout

Launch Vehicle - A U. S. Scout four-stage, solid propellant rocket, approximately 75 ft (23 m) in length with a launch weight of 47, 520 lb (21,555 kg), launched the San Marco satellite. Lift-off thrust was 145,942 lb (66,199 kg).

Program Overview - The internationally-sponsored San Marco D/L satellite, designed to make studies of the lower atmosphere, was launched from the San Marco Equatorial Range in Kenya, East Africa, by an Italian Air Force crew.

The launch, originally planned for March 18, 1988, was postponed until March 25 to permit replacement of a yaw rate gyro in the launch vehicle.

The San Marco D/L (the L stands for low orbit) was the fifth launch of the San Marco Project, a joint and cooperative space program between NASA and the Centro Ricerche Aerospaziali (CRA) (the Aerospace Research Center of the University of Rome, Italy).

Project Objectives - The primary objective of the San Marco D/L was to explore the possible relationship between solar activity and meteorological phenomena. A second objective was to determine the solar influence on low atmosphere phenomena through the thermosphere by obtaining simultaneous measurements necessary for the study of dynamic processes occurring in, and possible linking to, the troposphere, stratosphere, and thermosphere.

Spacecraft Description - The San Marco D/L was designed and built by the CRA. Its basic design was derived from the San Marco C configuration (launched in April 1971) with changes to accommodate a larger diameter. The San Marco D/L was a 38-in (96.5-cm) diameter sphere with four canted 18-in (48-cm) monopole antennas for telemetry and command.

Spacecraft Payload - The spacecraft carried five scientific instruments: one from Italy, one from West Germany, and three from the United States. The Italian instrument was the Neutral Atmosphere Density experiment, designed to measure drag forces on the satellite in orbit. The West German instrument is the Airglow Solar Spectrometer. It was designed to measure equatorial airglow, solar extreme ultraviolet radiation, solar radiation from the Earth's surface and from clouds, and the radiation from

interplanetary and intergalactic origin reaching the satellite.

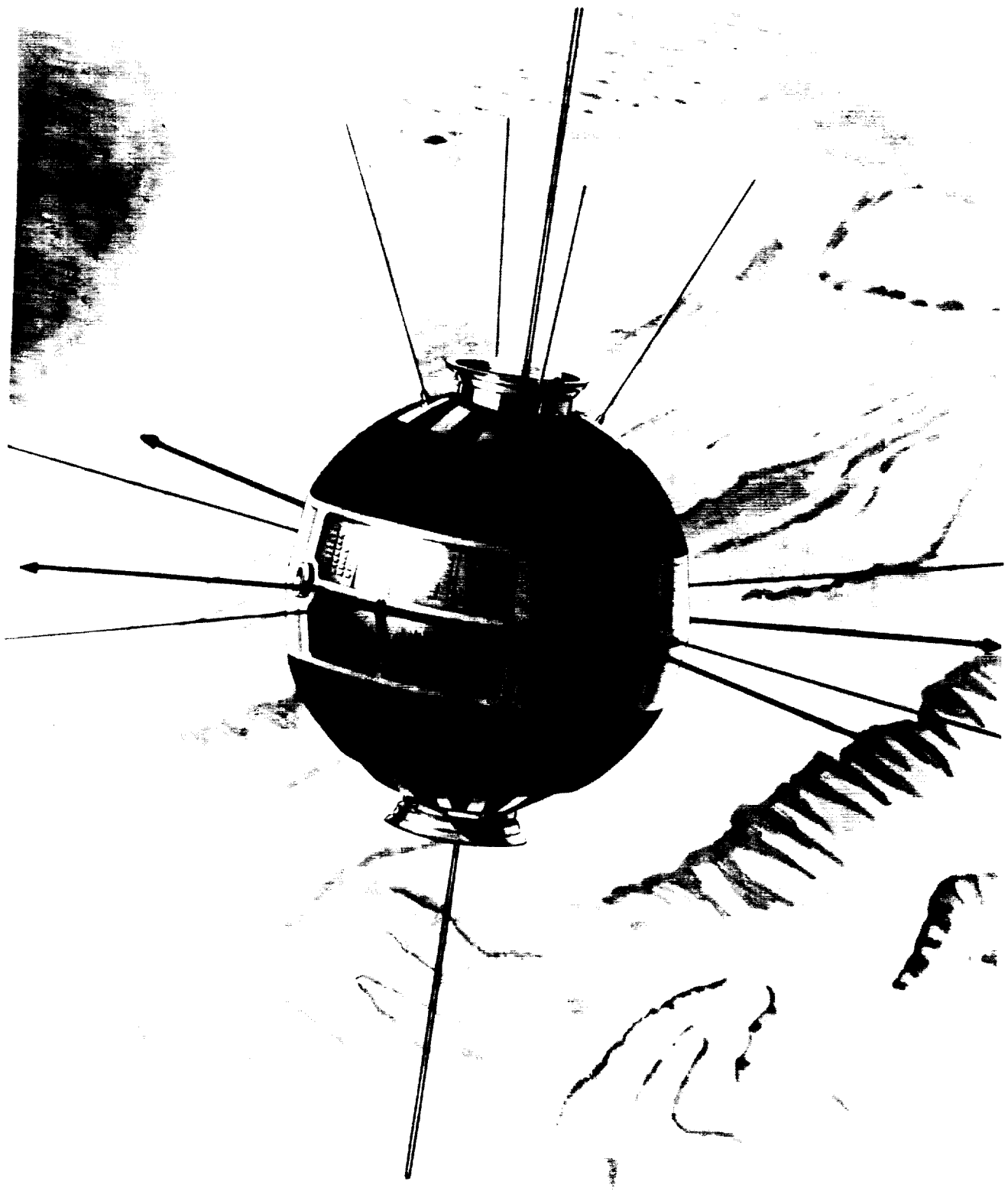
Two of the U.S. instruments were from NASA's Goddard Space Flight Center, Greenbelt, Maryland. They were the Wind and Temperature Spectrometer, which measured neutral winds, neutral particle temperatures, and concentrations of selected gases in the atmosphere; and the Three-Axis Electric Field Experiment, which measured the electric field surrounding the spacecraft in orbit.

The third U.S. instrument was the Ion Velocity Instrument from the University of Texas, Dallas. It was designed to measure the plasma (hot gases) concentration and ion winds surrounding the spacecraft in orbit.

Project Results - San Marco D/L burned up in the atmosphere during reentry December 6, 1988. The 522-lb (237 kg) spacecraft ended its more than eight months in orbit after 3,742 orbits, coming down over Central Zaire, at 8:11 p.m. EST.

Major Participants - In addition to being responsible for three of the instruments aboard the San Marco D/L, NASA supported the mission by providing equipment and services. Langley Research Center, Hampton, Virginia, provided the Scout vehicle. Scout is built by LTV Aerospace and Defense Company, Dallas, Texas.

A portion of Goddard's Multi-Satellite Operations Control Center was used to support the CRA Control Center, which had the prime responsibility. The CRA Control Center in Rome was responsible for obtaining and processing the spacecraft housekeeping data in real time, processing these data for raw value display and for analysis by the spacecraft controller, directing the activities for data acquisition and command, and coordinating the efforts of the mission operations system, which included orbit determination and mission scheduling.



The San Marco D/L spacecraft, an international satellite designed to study the lower atmosphere, contained five scientific instruments. One of the instruments was from Italy, one from West Germany, and three from the United States. The 522-lb (237-kg) spacecraft was launched from Italy's San Marco Equatorial Range off the coast of Kenya on a U.S.-supplied Scout rocket by an Italian launch crew on March 25, 1988.

Launch Vehicle - A four-stage Scout S-206 expendable launch vehicle launched the NOVA-II spacecraft. **NOVA-II**

Project Objective - The NOVA spacecraft provides precise navigation data for any ship equipped with a relatively simple receiving set. A precise fix to an accuracy of one-tenth of a mile can be obtained anywhere on the Earth's surface several times a day.

Spacecraft Description - The NOVA-II satellite weighed 385 lb (170.5 kg). The NOVA-II satellite was the latest in a series of improved Navy navigation satellites developed and built in 1975. The satellite contained a hydrazine kick motor to provide orbital adjustment capability.

Project Results - The Scout rocket, designed and built by the LTV Aerospace and Defense Company, Missile Division, Dallas, Texas, successfully launched NOVA II June 15, 1988, from Vandenberg Air Force Base, California. This was the 111th launch for Scout.

The Scout vehicle was managed by NASA's Langley Research Center, Hampton, Virginia.

**NATIONAL OCEANIC AND
ATMOSPHERIC
ADMINISTRATION
(NOAA-H) - Atlas**

**Advanced Very High Resolution
Radiometer (AVHRR)
TIROS Operational Vertical Sounder
System (TOVS)
Search and Rescue (SAR)
Argos Data Collection System (DCS)**

Launch Vehicle - An Atlas E., manufactured by General Dynamics Convair, launched the National Oceanic and Atmospheric Administration (NOAA)-H spacecraft.

Project Objectives - NOAA-11, identified as NOAA-H prior to launch, was designed to transmit data directly to users around the world for weather analysis. It is the third generation operational spacecraft for the National Environmental Satellite Data and Information Service (NESDIS) of the National Oceanic and Atmospheric Administration (NOAA). Ground facilities included NESDIS Command and Data Acquisition stations in Fairbanks, Alaska, and Wallops Island, Virginia; at NESDIS's Satellite Operations Control Center (SOCC) at Suitland, Maryland, and at a data receiving station operated by the Établissement d'Études et de Recherches Meteorologiques (EERM) in Lannion, France.

NOAA-11 carried special Search and Rescue (SAR) equipment in support of the COSPAS/SARSAT program, an international effort in which the primary partners are Canada, France, the Soviet Union, and the United States. The program began as a test and evaluation project in September 1982, following the launch of the Soviet navigational satellite, Cosmos 1383, on June 30, 1982. Between 1982 and October 1990, the program helped save more than 1,600 lives.

Spacecraft Description - NOAA-11 (NOAA-H) is the fourth of the Advanced TIROS-N spacecraft. These spacecraft are stretched versions of the original TIROS-N series of satellites and feature expanded capabilities for new measurement payloads. The spacecraft, including the apogee kick motor (AKM), in the launch configuration, was 193 in (491 cm) high and 74 in (188 cm) in diameter. It weighed 3,774 lb (1,712 kg). On orbit with the AKM and reaction control expendables consumed, the satellite weighed 3,370 lb (1,030 kg). The spacecraft was built by RCA Astro Electronics.

Spacecraft Payload -

- **Advanced Very High Resolution Radiometer (AVHRR)** - One of the primary instruments on NOAA-11 is the Advanced Very High Resolution Radiometer, provided by International Telephone and Telegraph,

for measuring energy emitted from the Earth's surface and cloud tops in the infrared and visible bands.

- **TIROS Operational Vertical Sounder System (TOVS)**
- Another of the primary instruments is the TIROS Operational Vertical Sounder System, which is made up of two separate instruments: the High Resolution Infrared Radiation Sounder (HIRS) and the Microwave Sounding Unit (MSU), provided by NASA's Jet Propulsion Laboratory, Pasadena, California. The MSU was designed to make temperature profiles of the atmosphere from the Earth's surface to 65,000 ft (19,800 m).
- **Search and Rescue (SAR)** - Provided by Canada and France, the SAR includes instruments with the capability of detecting existing emergency transmitters operating at 121.5 MHz in the very high frequency (VHF) band and 243.1 MHz in the ultra high frequency (UHF) band. The SAR equipment also can detect signals from 406 MHz transmitters. The locations of emergency transmissions are determined by using Doppler analysis techniques. Reports of distress signals are forwarded to Mission Control Centers in the Soviet Union, Canada, France, and the United States, and relayed to rescue coordination centers, which dispatch rescue units.
- **Argos Data Collection System (DCS)** - Provided by France, the DCS is a random access system that provides a means for locating floating terrestrial and atmospheric platforms. Approximately 400 platforms transmit data to the satellite. The information collected is transmitted to Earth for additional ground data processing.

Project Results - Launched September 24, 1988 from the Western Test Range in California, NOAA-H was placed in orbit with 98.7° inclination.

Major Participants -

NASA Headquarters, Washington, District of Columbia

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Contractors

General Dynamics Convair Division - Launch Vehicle
General Electric Astro-Electronics Division - Spacecraft
International Telephone & Telegraph - AVHRR
International Telephone & Telegraph - HIRS/2
Jet Propulsion Laboratory - MSU

Foreign Contributors

Centre National d'Études Spatiales (CNES), France - ARGOS
National Search and Rescue Secretariat (NSS), Canada - Search and Rescue Repeater (SARR)
CNES/France - Search and Rescue Processor (SARP)
Meteorology Office, United Kingdom - Stratospheric Sounding Unit

Launch Vehicle - The Space Transportation System (STS) - Space Shuttle Discovery deployed the Tracking and Data Relay Satellite (TDRS-C).

Program Overview - The first true aerospace vehicle, the space shuttle, takes off like a rocket. The winged orbiter then maneuvers around the Earth like a spaceship and lands on a runway like an airplane.

The space shuttle is designed to carry large and heavy payloads into Earth orbit. But unlike earlier manned spacecraft, which were good for only one flight, the shuttle orbiter and solid rocket boosters can be used again and again. Only the external tank is expended on each launch.

The shuttle also provides a new capability—checking out and repairing unmanned satellites in orbit, or returning them to Earth for more extensive overhauls. Satellites that the shuttle can orbit and maintain operate in the fields of environmental protection, energy, weather forecasting, navigation, fishing, farming, mapping, oceanography, and other spaceborne applications.

Many spacecraft operate in geosynchronous orbit. This is a flight path about 22,300 mi (35,888 km) above and aligned with the equator, with a speed in orbit that matches that of the Earth's surface below. From the ground, such satellites appear to hang motionless in the sky. The TDRS is taken into a low-Earth orbit by the shuttle, then on up to altitude by a powerful Inertial Upper Stage (IUS) booster.

The ability of the shuttle to land on a runway, unlike the expensive parachute descent and recovery at sea techniques used in Mercury, Gemini, and Apollo, saves both time and money. In addition, again unlike prior manned spacecraft, the most expensive shuttle components can be refurbished and made ready for another launch. The complex and expensive orbiter is designed to last for 100 flights minimum, and the solid rocket booster casings, engine nozzles, parachutes, etc., for 20 launches. The high cargo capacity and major component reusability of the shuttle make it unique among space vehicles. A space shuttle can be launched into equatorial orbit from the Kennedy Space Center (KSC), Florida.

TDRS-C - STS-26

Tracking and Data Relay Satellite (TDRS)

Physical Vapor Transport of Organic Solids (PVTOS)

Protein Crystal Growth (PCG)

Infrared Communications Flight Experiment (IRCFE)

Automated Directional Solidification Furnace (ADSF)

Aggregation of Red Blood Cells (ARC)

Isoelectric Focusing (IEF)

Mesoscale Lightning Experiment (MLE)

Phase Partitioning Experiment (PPE)

Earth-Limb Radiance Experiment (ELRAD)

Autonomous Supporting

Instrumentation System (OASIS)

Utilizing a Semi-Permeable Membrane to Direct Crystal Growth (SSIP 82-05)

The Effect of Weightlessness on Grain Formation (SSIP 82-04)

The orbiter is the only part of the space shuttle which has a name rather than a part number. The first orbiter built was the Enterprise, which was designed for flight tests in the atmosphere rather than operations in space. It is now at the Smithsonian Museum at Dulles Airport outside Washington, District of Columbia. Five operational orbiters have been built: in order, Columbia, Challenger, Discovery, Atlantis, and Endeavor.

- Space Shuttle Parts - The flight components of the space shuttle are the winged orbiter, an external tank, and two solid rocket boosters. The assembled Shuttle weighs about 4,500,000 lb (2,041,168 kg) at liftoff.

The orbiter carries the crew and payload. It is 122 ft (37 m) long and 57 ft (17 m) high, has a wingspan of 78 ft (24 m) and weighs from 168,000 to 175,000 lb (76,000 to 79,000 kg) empty. It is about the size and general shape of a DC-9 commercial jet airplane. Orbiters may vary slightly from unit to unit.

Each of the orbiter's three main engines produces 375,000 lb (1,668,000 newtons) thrust at sea level, and 470,000 lb (2,090,560 newtons) in the vacuum of space. They can burn for about eight minutes, while drawing 64,000 gal (242,240 L) of propellants each minute, and are used to take the orbiter to the edge of space and near-orbit velocity. The Orbital Maneuvering System (OMS) engines, burning nitrogen tetroxide for the oxidizer and monomethyl hydrazine for the fuel, supply the last increment of velocity to reach orbit and the thrust for in-orbit and de-orbit maneuvers. These propellants are from tanks carried in two pods at the upper rear of the orbiter.

The orbiter carries its cargo in a cavernous payload bay 60 ft (18.3 m) long and 15 ft (4.6 m) wide. The bay is flexible enough to provide accommodations for unmanned spacecraft in a variety of shapes and sizes and for fully equipped scientific laboratories such as the Spacelab. When the shuttle is fully developed as an operational vehicle, the total payload weight can reach 65,000 lb (29,500 kg).

The huge external tank is 154 ft (47 m) long and 28.6 ft (8.7 m) in diameter. It weighs a total of 1,667,677 lb (756,441 kg) at liftoff. Two inner tanks contain

140,000 gal (529,000 L) of liquid oxygen and 380,000 gal (1,438,300 L) of liquid hydrogen. The tank feeds these propellants to the main engines of the orbiter throughout the ascent into near-orbit. It is discarded and falls into an uninhabited stretch of ocean, the only major shuttle component expended on each launch.

The two solid rocket boosters are each 149.1 ft (45.4 m) high and 12.2 ft (3.7 m) in diameter. Each weighs 1,300,000 lb (589,670 kg). Their solid propellant consists of a mixture of aluminum powder, aluminum perchlorate powder, and a dash of iron oxide catalyst, held together with a polymer binder. They produce more than 3,000,000 lb (13,300,000 newtons) thrust at each liftoff. Together with the three main engines on the orbiter, this provides a total liftoff thrust of over 7,000,000 lb (31,000,000 newtons).

- **Crew and Passenger Accommodations** - The two-to-eight person crew occupies a two-level cabin at the forward end of the orbiter. The crew operates the vehicle from the upper level, the flight deck. The flight controls for the mission commander and pilot are at the front. A station at the rear, overlooking the cargo bay through two windows, contains the controls a mission specialist astronaut uses to operate the Remote Manipulator System arm which handles some of the cargo. Mission operations displays and controls are on the right side of the cabin, and payload controls on the left. The latter are operated by payload specialists, who are usually not career astronauts. The living, eating, and sleeping area for off-duty crew members, called the middeck, is located below the flight deck. It contains prepackaged food, a toilet, bunks, and other amenities.

Space flight is no longer limited to intensively trained, physically perfect astronauts. Experienced scientists and technicians can fly in support of their payloads. Crew members experience a designed maximum gravity load of 3g during launch, and less than 1.5g during reentry. These accelerations are about one-third the levels experienced on previous manned flights. Many other features of the space shuttle, such as a standard sea-level atmosphere, will make space flight more comfortable for the non-astronaut of the future.

- Typical Shuttle Mission - The rotation of the Earth has a significant bearing on the payload capabilities of the space shuttle. A due east launch from the Kennedy Space Center uses the Earth's rotation as a launch assist, because the ground is turning to the east at that point at a speed of 915 mi (1,473 km) per hour. This permits payloads on the fully developed shuttle to weigh as much as 65,000 lb (29,500 kg) when launched from KSC.

Spacecraft and other items of payload arrive at the Kennedy Space Center and are assembled and checked out in special buildings before being loaded into the orbiter. Each shuttle arrives as a set of component parts. The solid rocket booster propellant segments are received and checked out in a special facility, then taken to the Vehicle Assembly Building (VAB) and stacked on a mobile launcher platform to form two complete rockets. The external tank is received and prepared for flight in the VAB, then mated to the solid rockets. An orbiter is checked out in the Orbiter Processing Facility, then moved to the VAB and attached to the external tank. A giant crawler-transporter picks up the mobile launcher platform and the assembled shuttle and takes them to the pad. The shuttle remains on the platform until liftoff.

The orbiter's main engines ignite first and build to full power before the huge solid rockets ignite and liftoff occurs. The solid rockets burn out after about two minutes, are separated from the tank, and parachute into the ocean about 160 mi (258 km) from land. Two special recovery ships pull the parachutes out of the water and tow the rocket casings to land, where they are refurbished and sent back to the manufacturer to be refilled with propellant. The orbiter continues on to the edge of space—a total of about eight minutes of burn-time on the three main engines—where the empty tank is discarded. It continues around the world and breaks up over uninhabited ocean as it reenters the atmosphere. The two OMS engines then burn to inject the orbiter alone into low Earth orbit. Later OMS burns raise or adjust the orbit as necessary. A typical shuttle mission lasts from two to ten days, with a future growth potential of up to 30 days.

After deploying the payload spacecraft, operating the onboard scientific instruments, taking observations, etc., the orbiter reenters the atmosphere and lands, normally at either the Kennedy Space Center or Edwards AFB in California. Unlike prior manned spacecraft, which followed a ballistic trajectory, the orbiter has a cross-range capability (can move to the right or left of the straight line of its entry path) of about 1,270 mi (2,045 km). The landing speed is from approximately 212 to 226 mi (341 to 364 km) per hour. The orbiter is immediately "safed" by a ground crew with special equipment, the first step in the process which will result in another launch of this particular orbiter.

Project Objectives - The primary objectives of the STS-26 mission were to successfully deploy the Tracking and Data Relay Satellite-C/Inertial Upper Stage (TDRS-C/IUS) to perform all operations necessary to support the requirements of the Orbiter Experiment (OEX) Autonomous Supporting Instrumentation System (OASIS) payload and to conduct operations of the 11 middeck payloads.

The crew for this 26th mission of the Space Shuttle Program was Frederick H. Hauck, Capt., U.S. Navy, Commander; Richard O. Covey, Col., U.S. Air Force, Pilot; and John M. Lounge, George Nelson, Ph.D., and David C. Hilmer, Lt. Col., U.S. Air Force, Mission Specialists.

Spacecraft Payloads -

- Tracking and Data Relay Satellite (TDRS-C) - TDRS-C was the third TDRS advanced communications spacecraft to launch aboard the space shuttle. TDRS-1 launched during the Challenger's maiden flight in April 1983. The second, TDRS-B, was lost during the Challenger accident of January 1986.

Following arrival at geosynchronous altitude, TDRS-C (renamed TDRS-3 once it was in orbit) underwent a series of tests prior to being moved to its operational geosynchronous position over the Pacific Ocean south of Hawaii (171° W. longitude).

TDRS-3 and its identical sister satellite were designed to support up to 23 user spacecraft simultaneously, providing two basic types of service—a multiple access service which can simultaneously relay data from as many as 19 low-data-rate user spacecraft, and a single access service which will provide two high-data-rate communication relays from each satellite.

TDRS-3 was deployed from the orbiter approximately 6 hours after launch. Transfer to geosynchronous orbit was provided by the solid propellant Boeing/U.S. Air Force Inertial Upper Stage (IUS). Separation from the IUS occurs approximately 13 hours after launch.

The next TDRS spacecraft will replace the partially degraded TDRS-1 over the Atlantic. TDRS-1 will be moved to a location between the two operational TDRS spacecraft and serve as an on-orbit spare.

The concept of using advanced communications satellites was developed following studies in the early 1970s which showed that a system of communication satellites operated from a single ground terminal could support space shuttle and other low Earth-orbit space missions more effectively than a worldwide network of ground stations.

With the advent of the TDRS network, NASA's Space Tracking and Data Network ground stations have been significantly reduced in number. Three of the network's ground stations—Madrid, Spain; Canberra, Australia; and Goldstone, California—had already been transferred to the Deep Space Network managed by NASA's Jet Propulsion Laboratory, Pasadena, California.

The remaining ground stations, except those necessary for launch operations, were to be closed or transferred to other agencies after the successful launch and checkout of the next two TDRS satellites.

The ground station network, managed by the Goddard Space Flight Center, Greenbelt, Maryland, provided communications support for only a small fraction (typically 15-20 percent) of a spacecraft's orbital period. The Tracking and Data Relay Satellite System

(TDRSS), when established, will provide coverage for almost the entire orbital period of user spacecraft (about 85 percent).

A TDRSS ground terminal built at White Sands, New Mexico, provides a clear view to the TDRSS satellites, and weather conditions generally are good for communications.

The NASA ground terminal at White Sands provides the interface between the TDRSS and its network elements, which have their primary tracking and communication facilities at Goddard. Also located at Goddard is the Network Control Center, which provides system scheduling and is the focal point for NASA communications with the TDRSS satellites and network elements.

The TDRSS satellites are the largest communications spacecraft ever built, each weighing about 5,000 lb (2,268 kg). Each satellite spans more than 57 ft (17 m), measured across its solar panels. The single-access antennas, fabricated of molybdenum and plated with 14k gold, each measure 16 ft (5 m) in diameter and, when deployed, span more than 42 ft (13 m) from tip to tip.

The satellite consists of two modules. The equipment module houses the subsystems that operated the satellite. The telecommunications payload module has electronic equipment for linking the user spacecraft with the ground terminal. The TDRS has seven antennas and is the first designed to handle communications through S, Ku, and C frequency bands.

TRW Space and Technology Group, Redondo Beach, California, and the Harris Government Communications System Division, Melbourne, Florida, are the two primary subcontractors to CONTEL for spacecraft and ground terminal equipment, respectively. TRW also provided the software for the ground segment operation and integration and testing for the ground terminal and the TDRSS, as well as the systems engineering.

Primary users of the TDRSS network have been the space shuttle, Landsat Earth resources satellites, the Solar Mesosphere Explorer, the Earth Radiation Budget Satellite, the Solar Maximum Mission Satellite, and Spacelab.

- **Physical Vapor Transport of Organic Solids (PVTOS)** - Scientists from 3M Company flew an experiment on STS-26 to produce organic thin films with ordered crystalline structures and to study their optical, electrical, and chemical properties. The name of the experiment was derived from the method which is employed to produce organic crystals—vapor transport.
- **Protein Crystal Growth (PCG)** - PCG experiments were conducted during STS-26 to help advance a technology attracting intense interest from major pharmaceutical houses, the biotech industry, and agrichemical companies.

A team of industry, university, and government research investigators explored the potential advantages of using protein crystals grown in space to determine the complex, three-dimensional structure of specific protein molecules.

- **Infrared Communications Flight Experiment (IRCFE)**
- Using the same kind of invisible light that remotely controls our home television sets and video cassette recorders, Mission Specialist George “Pinky” Nelson conducted experimental voice communications with his STS-26 crewmates via infrared, rather than standard radio frequency waves.

On a noninterfering basis and during noncritical normal crew activities requiring voice operations, Nelson unstowed the IRCFE from the middeck locker and began a minimum of 2 hours of experimentation from both flight and middeck locations.

- **Automated Directional Solidification Furnace (ADSF)**
- The ADSF is a special space furnace developed and managed by Marshall Space Flight Center, Huntsville, Alabama. It is designed to demonstrate the possibility of producing lighter, stronger, and better-performing magnetic composite materials in a microgravity environment.

- **Aggregation of Red Blood Cells (ARC)** - Blood samples from donors with such medical conditions as heart disease, hypertension, diabetes, and cancer flew in the ARC experiment developed by Australia and managed by Marshall Space Flight Center.

The experiment was designed to provide information on the formation rate, structure, and organization of red cell clumps, as well as on the thickness of whole blood cell aggregates at high and low flow rates. It helped determine if microgravity can play a beneficial role in new and existing clinical research and medical diagnostic tests.

- **Isoelectric Focusing (IEF)** - IEF was a type of electrophoresis experiment which separated proteins in an electric field according to their surface electrical charge.
- **Mesoscale Lightning Experiment (MLE)** - MLE was an experiment designed to obtain nighttime images of lightning in an attempt to better understand the effects of lightning discharges on each other, on nearby storm systems, and on storm microbursts and wind patterns and to determine interrelationships over an extremely large geographical area.
- **Phase Partitioning Experiment (PPE)** - One of the most important aspects of biotechnical and biomedical technology involves separation processes. Cell types producing important compounds must be separated from other cell types. Cells with important biomedical characteristics must be isolated to study those characteristics. This experiment involved a separation termed two-phase partitioning.

The PPE was designed to fine tune understanding of the role gravity and other physical forces play in separating, i.e., partitioning biological substances between two unmixable liquid phases.

- **Earth Limb Radiance Experiment (ELRAD)** - ELRAD was an experiment developed by the Barnes Engineering Company designed to photograph the Earth's "horizon twilight glow" near sunrise and sunset.

- Orbiter Experiments Autonomous Supporting Instrumentation System (OASIS) - The OASIS was designed to collect and record a variety of environmental measurements during various in-flight phases of the orbiter. The primary device is a large tape recorder which is mounted on the aft, port side of the orbiter. The OASIS recorder can be commanded from the ground to store information at a low, medium, or high data rate.

The information was used to study the effects on the orbiter of temperature, pressure, vibration, sound, acceleration, stress, and strain. It was also used to assist in the design of future payloads and upper stages.

SHUTTLE STUDENT INVOLVEMENT PROGRAM (SSIP)

- Semi-Permeable Membrane to Direct Crystal Growth - This experiment attempted to control crystal growth through the use of a semi-permeable membrane.
- Weightlessness on Grain Formation and Strength in Metals - This experiment proposed to heat a titanium alloy metal filament to near the melting point to observe the effect that weightlessness has on crystal reorganization within the metal.

Major Participants

NASA Headquarters, Washington, District of Columbia

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The STS-26 crewmembers are astronauts Frederick H. (Rick) Hauck (right front), mission commander; Richard O. Covey (left front), pilot; and mission specialists (left to right) David C. Hilmers, George D. (Pinky) Nelson, and John M. (Mike) Lounge.

1989 Missions

TDRS-D - STS-29

**Tracking and Data Relay Satellite
(TDRS)**

**Space Station Heat Pipe Advanced
Radiator Element (SHARE)**

**Space and Life Sciences Training
Program Chromosome and Plant
Cell Division in Space
(CHROMEX)**

Protein Crystal Growth (PCG)

IMAX Motion Pictures

**Air Force Maui Optical Site (AMOS)
Test**

**Autonomous Supporting
Instrumentation System (OASIS)**

Orbiter Experiment (OEX)

**Shuttle Student Involvement Projects
(SSIP)**

Launch Vehicle - The Space Transportation System (STS) - Space Shuttle Discovery deployed the Tracking and Data Relay Satellite (TDRS-D).

Program Overview - See page 10.

Project Objectives - This was the 28th flight of the space shuttle and the eighth flight of the OV-103 orbiter, Discovery. The primary objective of the STS-29 mission was to successfully deploy the Tracking and Data Relay Satellite-D satellite. Secondary objectives were to perform all operations necessary to support the requirements of the Orbiter Experiment (OEX) Autonomous Supporting Instrumentation System (OASIS), Space Station Heat Pipe Advanced Radiator Element (SHARE), Protein Crystal Growth (PCG), Space and Life Sciences Training Program Chromosome and Plant Cell Division in Space (CHROMEX), IMAX Camera, Chicken Embryo Development in Space, Effects of Weightlessness in Space Flight on the Healing of Bones, and the Air Force Maui Optical Site (AMOS) calibration test payloads.

The crew for this mission was Michael L. Coats, Capt., U.S. Navy, Commander; John E. Blaha, Col., U.S. Air Force, Pilot; Robert C. Springer, Col., U.S. Marine Corps, Mission Specialist 1; James F. Buchli, Col., U.S. Marine Corps, Mission Specialist 2; and James P. Bagian, M.D., Mission Specialist 3.

Spacecraft Payloads -

- **Tracking and Data Relay Satellite (TDRS-D)** - TDRS-D was the fourth TDRS communications spacecraft to be launched aboard the space shuttle and completed the constellation of on-orbit satellites for NASA's advanced space communications system. TDRS-1 was launched during Challenger's maiden flight in April 1983. The second was lost during the Challenger accident in January 1986. TDRS-3 was launched successfully on September 29, 1988, during the landmark mission of Discovery, which returned the space shuttle to flight.

After its launch, TDRS-D was designated TDRS-4. Following its arrival at geosynchronous orbit and a series of tests, it replaced the partially degraded TDRS-1 over the Atlantic. TDRS-1 then was moved to

79° W. longitude, above the Equator, to be used as an on-orbit spare.

The two operational TDRS—those located at 41° and 171° W. longitude—support up to 23 user spacecraft simultaneously and produce two basic types of service: a multiple-access service that simultaneously relays data from as many as 19 low-data-rate user spacecraft; and a single-access service that provides two high-data-rate communications relays from each satellite.

TDRS-4 was deployed from the orbiter about 6 hours after launch. The solid-propellant Boeing/U.S. Air Force Inertial Upper State (IUS) transferred the satellite to geosynchronous orbit. IUS separation occurred about 13 hours after launch.

The concept of using advanced communications satellites was developed in early 1970s, following studies showing that a system of communications satellites operated from a single ground terminal could support space shuttle and other low-Earth-orbit space missions more effectively than a worldwide network of ground stations. The current ground station network could only provide support for a small fraction—typically 15 to 20 percent—of the orbits of user spacecraft. The modern, space-based TDRS network covered at least 85 percent of the orbits.

The new system also facilitated a much higher information flow rate between the spacecraft and the ground. This was particularly important as NASA resumed regular Shuttle flights and launched satellites with high data rates.

NASA's Space Tracking and Data Network ground stations, managed by the Goddard Space Flight Center, Greenbelt, Maryland, was reduced significantly after the satellite communications system became operational. Three of the network's ground stations—Madrid, Spain; Canberra, Australia; and Goldstone, California—had already been transferred to the Deep Space Network, managed by the Jet Propulsion Laboratory, Pasadena, California. The remaining ground stations, except those needed for launch operations, were closed or transferred to other agencies.

The White Sands Ground Terminal (WSGT) is situated on a NASA test site located between Las Cruces and White Sands, New Mexico. A colocated NASA facility provided the interface between the WSGT and the NASA space network facilities at Goddard Space Flight Center. A technologically advanced second ground terminal is being built at White Sands to provide back-up and additional capability.

The tracking and data relay satellites are the largest communications spacecraft ever built and the first to handle satellite communications through the S and Ku frequency bands. Each weighs about 2 tons (1,814 kg), spans almost 60 ft (18 m) across its solar panels, and contains seven antennas. Each of the two gold-plated, single-access antennas measures 16 ft (5 m) in diameter and, when fully deployed, spans more than 42 ft (13 m) from tip to tip.

The combination of satellites and ground facilities is referred to as the Tracking and Data Relay Satellite System (TDRSS). TRW Space and Technology Group, Redondo Beach, California, designed and built the spacecraft and software for ground terminal operation, and integrated and tested the system. Harris Government Communications Systems Division, Melbourne, Florida, designed and built the ground terminal equipment.

The space shuttle, LANDSAT Earth Resources satellites, Solar Mesosphere Explorer, Earth Radiation Budget Satellite, Solar Maximum Mission satellite, and Spacelab have been primary users of TDRSS.

- Space Station Heat Pipe Advanced Radiator Element (SHARE) - SHARE flight experiment was mounted on the starboard sill of the Orbiter's payload bay with a small instrumentation package mounted in the forward payload bay. The goal of the experiment was to test a first-of-its kind method for a potential cooling system of Space Station Freedom.
- Space and Life Sciences Training Program Chromosome and Plant Cell Division in Space (CHROMEX) - This experiment was to determine whether the roots of a plant in microgravity will develop similarly to those on Earth. Root-free shoots

of the plants daylily and haplopappus were used. The experiment was to determine whether:

- The normal rate, frequency, and patterning of cell division in the root tops can be sustained in space;
 - The chromosomes and genetic makeup is maintained during and after exposure to space flight conditions; and
 - Aseptically grown tissue cultured materials will grow and differentiate normally in space.
- Protein Crystal Growth Experiment (PCG) - STS-29 protein crystal growth experiments were expected to help advance a technology attracting intense interest from major pharmaceutical houses, the biotech industry, and agricultural companies.

A team of industry, university, and government research investigators explored the potential advantages of using protein crystals grown in space to determine the complex, three-dimensional structure of specific protein molecules.

Knowing the precise structure of these complex molecules provides the key to understanding their biological function and could lead to methods of altering or controlling the function in ways that may result in new drugs.

- IMAX - The IMAX project is a collaboration between NASA and the Smithsonian Institution's National Air and Space Museum to document significant space activities using the IMAX film medium. This system, developed by the IMAX Systems Corporation, Toronto, Canada, uses specially-designed 70mm film cameras and projectors to record and display very high definition large-screen color motion picture images.
- Air Force Maui Optical Site Calibration Test (AMOS)
 - The AMOS tests allow ground-based electro-optical sensors located on Mt. Haleakala, Maui, Hawaii, to collect imagery and signature data of the orbiter during cooperative overflights.
- Orbiter Experiments Autonomous Supporting Instrumentation (OASIS) - Special instrumentation

to record the environment experienced by Discovery during the STS-29 mission is mounted in the orbiter payload bay.

Called OASIS, the instrumentation is designed to collect and record a variety of environmental measurements during various in-flight phases of the orbiter. The primary device is a large tape recorder mounted on the aft port side of the orbiter. The OASIS recorder can be commanded from the ground to store information at a low, medium, or high data rate. After Discovery's mission is over, the tapes will be removed for analysis.

The information will be used to study the effects on the orbiter of temperature, pressure, vibration, sound, acceleration, stress, and strain. It also will be used to assist in the design of future payloads and upper stages.

STUDENT EXPERIMENTS

- Chicken Embryo Development in Space, SE83-9 - This experiment, proposed by John. C. Vellinger, formerly of Jefferson High School, Lafayette, Indiana, will determine the effects of space flight on the development of fertilized chicken embryos.

Vellinger's goal was to determine whether a chicken embryo can develop normally in a weightless environment.

- The Effects of Weightlessness on the Healing Bone, SE82-8 - This was an experiment proposed by Andrew I. Fras, formerly of Binghamton High School, New York, to establish whether the environmental effects of space flight inhibit bone healing.

Project Results - The Tracking and Data Relay Satellite was deployed on time, and the planned solid rocket motor burns were performed. One reaction control system firing also was performed. The satellite was successfully put into a geosynchronous orbit. All TDRS appendages were deployed nominally, and the satellite was placed in the planned operational position of 150° W. longitude for checkout.

All payloads performed successfully throughout the mission, except the SHARE. The SHARE payload was unable to achieve normal operations because of the presence of vapor bubbles in the liquid channels. A number of unplanned orbiter maneuvers were executed, but these were only partially successful in dislodging the bubble. The Orbiter Experiment (OEX) Autonomous Supporting Instrumentation System (OASIS) payload operated nominally. Middeck payloads and payload integration hardware operated satisfactorily through the mission.

Major Participants

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Ames Research Center, Mountain View, California

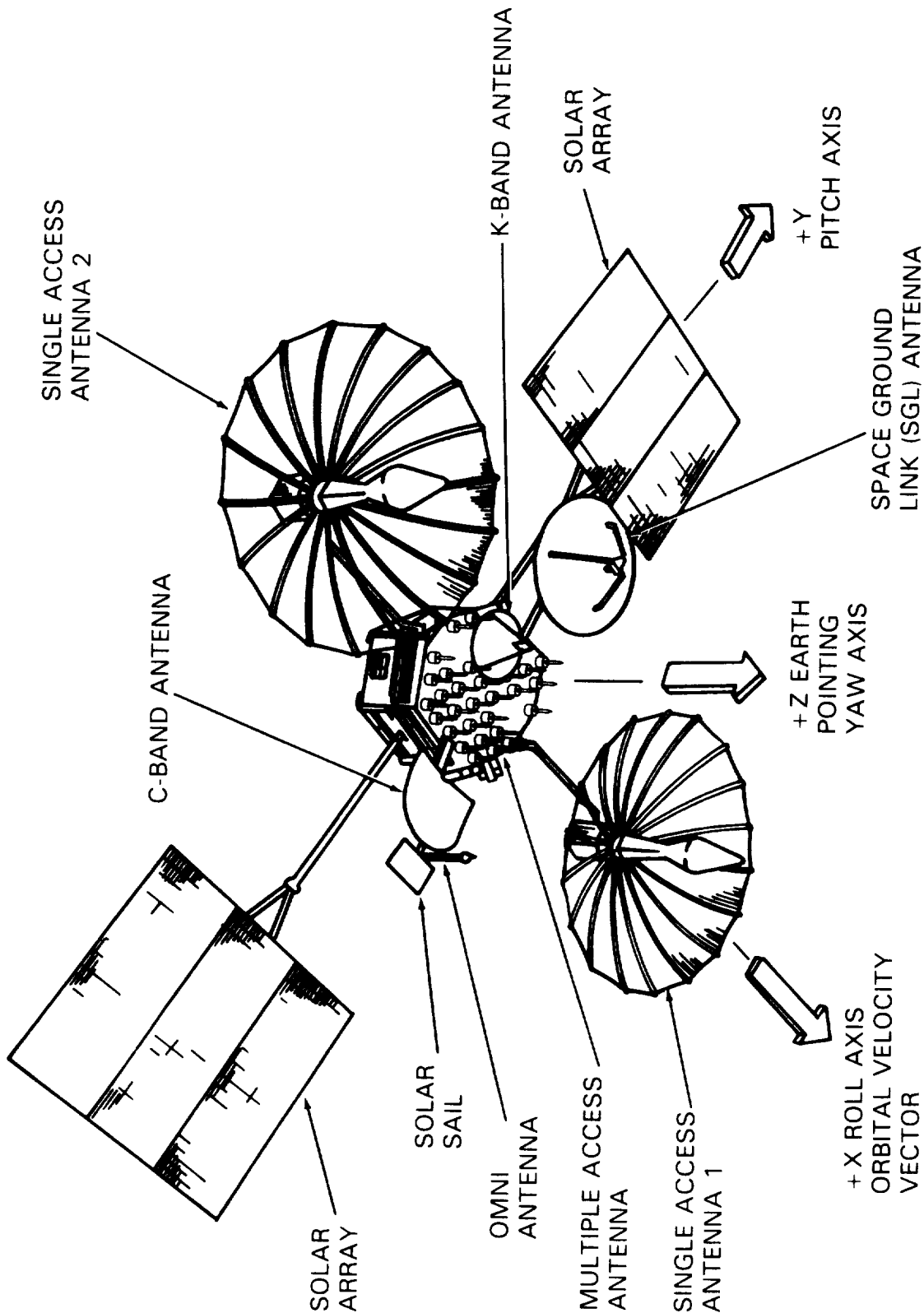
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TDRS SPACECRAFT ON-ORBIT CONFIGURATION

At launch aboard the shuttle, the TDRS solar panels and antennas are compactly folded to enable it to fit into the shuttle cargo bay. When unfolded after deployment, the satellite measures 57 ft (17.4 m) from the outer edge of one solar panel to the outer edge of the other (about the height of a 5-story building), and 46 ft (14 m) from the outermost edge of the other.

MAGELLAN - STS-30

Magellan

Mesoscale Lightning Experiment (MLE)

Fluids Experiment Apparatus (FEA) Air Force Maui Optical Site (AMOS)

Launch Vehicle - The Space Transportation System (STS) - Space Shuttle Atlantis launched the Magellan spacecraft.

Program Overview - See page 10.

Project Objectives - The 29th flight of America's Space Transportation System had as its primary objective to successfully deploy the Magellan Venus-exploration spacecraft into low-Earth orbit. Secondary objectives were to perform all operations necessary to support the requirements of the Fluids Experiment Apparatus (FEA) and Mesoscale Lightning Experiment (MLE), both middeck experiments, and the Air Force Maui Optical Site (AMOS) calibration test.

The crew for this 30th mission of the space shuttle program were David M. Walker, Commander; Ronald J. Grabe, Pilot; and three mission specialists: Norman E. Thagard, M.D.; Mary L. Cleave; and Mark C. Lee.

Spacecraft Payloads -

- **Primary payload:** The primary payload, the Magellan spacecraft, is the first planetary probe to be launched from a space shuttle and the first planetary spacecraft to be launched in nearly 11 years.

Magellan will map up to 90 percent of the surface of Venus to a higher degree of resolution than ever done before. This spacecraft's primary science instrument is an imaging radar, called Synthetic Aperture Radar (SAR). In addition to mapping, precise tracking of Magellan radio signals will improve current knowledge of the Venusian gravity field.

The Magellan spacecraft was designed and constructed by Martin Marietta Astronautics Group, Denver, Colorado. The height of the spacecraft is 21 ft (6 m). It is 15 ft (5 m) in diameter and weighs 7,604 lb (3,449 kg).

Magellan's high-gain antenna serves two purposes, it is the primary antenna for the telecommunications system to send data back to Earth, and it is also used as the antenna for the synthetic aperture radar.

There is also a cone-shaped medium-gain antenna used for receiving commands by and sending engineering data from Magellan during the 15-month cruise from Earth.

Power for the spacecraft and the experiments is provided by two solar panels with a total area of 12.6 square meters. The array is capable of producing 1,200 watts. Two 30-amp hour, 26-cell nickel cadmium batteries provide power when the spacecraft is in the shadow of the planet and allow normal spacecraft operations independent of solar illumination. The batteries remain charged by using power provided by the solar arrays.

The synthetic aperture radar will be used for Venus mapping because it can penetrate the thick clouds covering the planet. Optical photography cannot penetrate the clouds. SAR will create high-resolution images by using computer processing on Earth to simulate a large antenna on the spacecraft. The onboard radar system will operate as though it has a huge antenna, hundreds of meters long. The antenna is actually 12 ft (4 m) in diameter.

The radar system was built by the Hughes Aircraft Company, Space and Communications Group.

- Secondary Payloads -
 - The Mesoscale Lightning Experiment (MLE) is designed to obtain nighttime images of lightning in an attempt to better understand what effects lightning discharges have on each other, on nearby storm systems, on storm microbursts and wind pattern, and other interrelationships over an extremely large geographical area. The MLE will employ shuttle payload bay cameras to observe lightning discharges at night from active storms. Using the shuttle's payload bay color video camera augmented by a 35mm handheld still-picture camera with 400 ASA film, the shuttle cameras' 40-degree field of vision will cover an area roughly 200 by 150 nautical miles directly below the shuttle. The MLE had several photographic

opportunities, but very little photography was obtained during the passes.

- Fluids Experiment Apparatus (FEA) is a joint endeavor between Rockwell International, through its Space Transportation Systems Division, Downey, California, and NASA's Office of Commercial Programs in the field of floating zone crystal growth research. FEA is designed to perform materials processing research in the microgravity environment of spaceflight. The FEA contained four indium samples for processing during the mission. Processing of sample five, the final sample, was not completed. Sample two was not flown because of low pressure in the sample.
- The Air Force Maui Optical Site (AMOS) experiment allows ground-based electro-optical sensors located on Mt. Haleakala, Maui, Hawaii, to collect imagery and signature data of the orbiter during cooperative overflights. Five daylight Reaction Control System (RCS) tests were scheduled for AMOS. The tests on orbit 49 were completely successful and the tests on orbit 34 were partially successful.

Project Results - Atlantis was launched from the Kennedy Space Center, Florida, at 1:47 p.m., EST, on May 4, 1989. Landing was on May 8, with a total mission duration of 96 hours, 57 minutes.

Atlantis' crew successfully deployed the mission's primary payload Magellan, six hours, fourteen minutes into the mission. The Inertial Upper Stage (IUS) solid rocket motor (SRM)-1 burn was performed as planned exactly one hour after deployment of Magellan. The SRM-1 was satisfactorily separated and SRM-2 ignition occurred five minutes later, or seven hours, 19 minutes into the mission. Magellan spacecraft successfully separated from the SRM-2 and Magellan was then on its planned trajectory for the 15-month trip to Venus.

Major Participants

NASA Headquarters, Washington, District of Columbia

Dale D. Myers, Acting Administrator; Richard H. Truly, Associate Administrator for Space Flight; George W. S. Abbey, Deputy Associate Administrator for Space Flight; Arnold D. Aldrich, Director, National Space Transportation Program; David L. Winterhalter, Director, Systems Engineering and Analyses; Gary E. Krier, Director, Operations Utilization; Joseph B. Mahon, Deputy Associate Administrator for Space Flight (Flight Systems); Charles R. Gunn, Director, Unmanned Launch Vehicles and Upper Stages; George A. Rodney, Associate Administrator for Safety, Reliability, Maintainability, and Quality Assurance; Dr. Lennard A. Fisk, Associate Administrator for Space Sciences and Applications; Samuel W. Keller, Deputy Associate Administrator for Space Sciences and Applications; Dr. Geoffrey A. Briggs, Director, Solar Systems Exploration Division; Dr. William L. Piotrowski, Magellan Program Manager; Dr. Joseph Boyce, Magellan Project Scientist

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Jet Propulsion Laboratory, Pasadena, California

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NAVY FLEET SATELLITE COMMUNICATIONS/ FLTSATCOM (F-8) - Atlas

Launch Vehicle - The Navy FLTSATCOMs are launched aboard Atlas Centaur (AC-68) expendable launch vehicles. After reorientation of the satellite, a solid propellant rocket motor aboard the spacecraft is fired to circularize the orbit at an Earth-synchronous altitude. This was the 68th launch of an Atlas Centaur. NASA is reimbursed for all costs of the Atlas Centaur and launch services by the Department of Defense (DOD).

Project Objectives - The objective was to place FLTSATCOM F-8 into a geostationary orbit above the equator to provide two-way communications in the 240 to 400 MHz frequency band, between any two points on Earth visible from its orbital location. The spacecraft had a design life of five years.

The FLTSATCOM program is managed by the Naval Space and Warfare Systems Command. The Air Force Space Division, Los Angeles, California, is responsible for production, launch vehicle/spacecraft integration, and tracking and data acquisition.

The FLTSATCOM satellites are the spaceborne portion of a worldwide DOD network to enable communications between naval aircraft, ships, submarines, ground stations, Strategic Air Command elements, and presidential command networks.

Spacecraft Description - The FLTSATCOM satellite system provides 23 ultra high frequency (UHF) communication channels and one super high frequency (SHF) channel. The FLTSATCOM F-8 satellite also carried an experimental extra high frequency (EHF) package.

Spacecraft Payload - The FLTSATCOM spacecraft consisted of two major hexagonal elements, a payload module and a spacecraft module. A majority of the electronic equipment was mounted on 12 panels that enclosed the payload and spacecraft modules.

The payload module, which was fastened to the six corners of the spacecraft module, contained the UHF and X-band communications equipment and antennas. The UHF transmit antenna was made of ribs and mesh that opened like an umbrella, and the receive antenna was a separate deployable helix.

The spacecraft module contained the Earth sensors, apogee kick motor, attitude and velocity control, telemetry tracking and command (TT&C), electrical power distribution, and the solar array.

The solar array was folded around the spacecraft module prior to its final position in orbit where it was deployed by spring loaded hinges. It was exposed to sunlight in both the deployed and folded positions.

During the transfer orbit operations and through kick motor burn, the spacecraft was spin stabilized. After apogee kick and motor burn, the spacecraft was de-spun, solar arrays and UHF antenna were deployed, and the Sun and Earth were acquired. In normal on-orbit operations, the spacecraft was pointed at the center of the Earth by the Earth sensors, roll/yaw jets, and a reaction wheel. The solar array was usually normal to the orbit plane and was rotated at a uniform rate to point at the Sun. Rotation was achieved by a clocked drive with command correction available.

A redundant monopropellant hydrazine thruster system was provided for spacecraft control and velocity maneuvers. A solid propellant apogee kick motor injected the spacecraft into a circular, near synchronous orbit.

Solar arrays and batteries interfaced with a command electrical power bus which distributed primary power to the subsystem equipment converters.

Project Results - The satellite was successfully launched from Cape Canaveral Air Force Station, Florida, on September 25, 1989

Major Participants -

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Lewis Research Center, Cleveland, Ohio

Lawrence J. Ross, Director; Vern J. Weyers, Director, Space Flight Systems; John W. Gibb, Atlas/Centaur Project Manager; Steven V. Szabo, Jr., Director of Engineering; Edwin R. Procasky, Chief Systems Engineering Office; Richard E. Orzechowski, FLTSATCOM Mission Project Manager

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Contractors

General Dynamics Convair Division - Launch Vehicle

Honeywell Aerospace Division - Centaur Guidance Inertial Measurement Group

Pratt and Whitney Aircraft Group - Centaur RL-10 Engines

Teledyne Industries, Inc. - Digital Computer Unit

Rocketdyne Division, Rockwell International Corp. - MA-5 Propulsion System

GALILEO - STS-34

Galileo

**Solar Backscatter Ultraviolet
Spectrometer (SSBUV)**

**Growth Hormone Concentration and
Distribution in Plants (GHCD)**

Polymer Morphology (PM)

**Mesoscale Lightning Experiment
(MLE)**

IMAX Motion Pictures

Air Force Maui Optical Site (AMOS)

Sensor Technology Experiment (STEX)

Launch Vehicle - The Space Transportation System (STS) - Space Shuttle Atlantis deployed the Galileo spacecraft.

Program Overview - See page 10.

Spacecraft Payloads -

- Galileo - Galileo is a NASA spacecraft mission to Jupiter to study the planet's atmosphere, satellites, and surrounding magnetosphere. It was named for the Italian renaissance scientist who discovered Jupiter's major moons by using the first astronomical telescope.

The mission was the first to make direct measurements from an instrumented probe within Jupiter's atmosphere and the first to conduct long-term observations of the planet and its magnetosphere and satellites from orbit around Jupiter. It will be the first orbiter and atmospheric probe for any of the outer planets. On the way to Jupiter, Galileo also will observe Venus, the Earth-moon system, one or two asteroids, and various phenomena in interplanetary space.

Galileo was boosted into low-Earth orbit by the Space Shuttle Atlantis and then boosted out of Earth orbit by a solid rocket Inertial Upper Stage. The spacecraft will fly past Venus and twice by the Earth, using gravity assists from the planets to pick up enough speed to reach Jupiter. Travel time from launch to Jupiter is a little more than six years.

In December, 1995, the Galileo atmospheric probe will conduct a brief, direct examination of Jupiter's atmosphere, while the larger part of the craft, the orbiter, begins a 22-month, 10-orbit tour of major satellites and the magnetosphere, including long-term observations of Jupiter throughout this phase.

The two-ton (1,814 kg) Galileo orbiter spacecraft carries nine scientific instruments. There are another six experiments on the 750 lb (340 kg) probe. The spacecraft radio link to Earth serves as an additional instrument for scientific measurements. The probe's scientific data will be relayed to Earth by the orbiter during the 75-minute period while the probe is

descending into Jupiter's atmosphere. Galileo will communicate with its controllers and scientists through NASA's Deep Space Network, using tracking stations in California, Spain, and Australia.

The Galileo mission and systems were designed to investigate three broad aspects of the Jupiter system: the planet's atmosphere, the satellites, and the magnetosphere. The spacecraft was in three segments to focus on these areas: the atmospheric probe; a non-spinning section of the orbiter carrying cameras and other remote sensors; and the spinning main section of the orbiter spacecraft which included the propulsion module, the communications antennas, main computers and most support systems as well as the fields and particles instruments, which sense and measure the environment directly as the spacecraft flies through it.

Galileo communicates with Earth via NASA's Deep Space Network (DSN), which has a complex of large antennas with receivers and transmitters located in the California desert, another in Australia, and a third in Spain, linked to a network control center at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California. The spacecraft receives commands, sends science and engineering data, and is tracked by Doppler and ranging measurements through this network.

At JPL, about 275 scientists, engineers, and technicians supported the mission at launch, increasing to nearly 400 for Jupiter operations including support from the German retropropulsion team at their control center in Germany. Their responsibilities included spacecraft command, interpreting engineering and scientific data from Galileo to understand its performance, and analyzing navigation data from the DSN. The controllers used a set of complex computer programs to help them control the spacecraft and interpret the data.

- SSBUV - The Shuttle Solar Backscatter Ultraviolet (SSBUV) instrument was developed by NASA to calibrate similar ozone measuring space-based instruments on the National Oceanic and Atmospheric

Administration's TIROS satellites (NOAA-9 and -11).

The SSBUV will help scientists solve the problem of data reliability caused by calibration drift of solar backscatterultraviolet (SBUV) instruments in orbiting spacecraft. The SSBUV uses the space shuttle's orbital flight path to assess instrument performance by directly comparing data from identical instruments aboard the TIROS spacecraft, as the shuttle and the satellite pass over the same Earth location within a 1-hour window. These orbital coincidences can occur 17 times per day.

- GHCD - The Growth Hormone Concentration and Distribution in Plants (GHCD) experiment was designed to determine the effects of microgravity on the concentration, turnover, properties, and behavior of the plant growth hormone, Auxin, in corn shoot tissue (Zea Mays).
- PM - The Polymer Morphology (PM) experiment was a 3M-developed organic materials processing experiment designed to explore the effects of microgravity on polymeric materials as they are processed in space.
- STUDENT EXPERIMENT - Zero Gravity Growth of Ice Crystals From Supercooled Water With Relation to Temperature (SE82-15) - This experiment, proposed by Tracy L. Peters, formerly of Ygnacio High School, Concord, California, will observe the geometric ice crystal shapes formed at supercooled temperatures, below 0° Celsius, without the influence of gravity.
- MLE - The space shuttle again carried the Mesoscale Lightning Experiment (MLE), designed to obtain nighttime images of lightning in order to better understand the global distribution of lightning, the interrelationships between lightning events in nearby storms, and relationships between lightning, convective storms, and precipitation.

A better understanding of the relationships between lightning and thunderstorm characteristics can lead to the development of applications in severe storm

warning and forecasting, and early warning systems for lightning threats to life and property.

- **IMAX** - The IMAX project is a collaboration between NASA and the Smithsonian Institution's National Air and Space Museum to document significant space activities using the IMAX film medium. This system, developed by the IMAX Systems Corp., Toronto, Canada, used specially designed 70mm film cameras and projectors to record and display very high definition large-screen color motion pictures.

The IMAX camera was used on this mission to cover the deployment of the Galileo spacecraft and to gather material on the use of observations of the Earth from space for future IMAX films.

- **AMOS** - The Air Force Maui Optical Site (AMOS) tests allowed ground-based electro-optical sensors located on Mt. Haleakala, Maui, Hawaii, to collect imagery and signature data of the orbiter during cooperative overflights. Scientific observations made of the orbiter while performing Reaction Control System thruster firings, water dumps, or payload bay light activation were used to support the calibration of the AMOS sensors and the validation of spacecraft contamination models. AMOS tests have no payload-unique flight hardware and only require that the orbiter be in predefined attitude operations and lighting conditions.
- **STEX** - The Sensor Technology Experiment (STEX) was a radiation detection experiment designed to measure the natural radiation background. The STEX was a self-contained experiment with its own power, sensor, computer control and data storage. A calibration pack, composed of a small number of passive threshold reaction monitors, was attached to the outside of the STEX package.

Major Participants

NASA Headquarters, Washington, District of Columbia

Richard H. Truly, NASA Administrator; James R. Thompson, Jr., NASA Deputy Administrator; William B. Lenoir, Acting Associated Administrator for Space Flight;

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GALILEO ORBITER AND PROBE SCIENTIFIC INVESTIGATORS

Probe

Atmospheric Structure; A. Seiff, Ames Research Center; temperature, pressure density, molecular weight profiles

Neutral Mass Spectrometer; H. Neimann, Goddard Space Flight Center; chemical composition

Helium Abundance; U. von Zahn, Bonn University, Federal Republic of Germany; helium/hydrogen ratio

Nephelometer; B. Ragent, Ames Research Center clouds, solid/liquid particles

Net Flux Radiometer; L. Stromovsky, University of Wisconsin-Madison; thermal/solar energy profiles

Lightning/Energetic Particles; L. Lanzerotti, Bell Laboratories; detect lightning, measuring energetic particles

Orbiter (Despun Platform)

Solid-State Imaging Camera; M. Belton, National Optical Astronomy Observatories (Team Leader); Galilean satellites at 1-km resolution or better

Near-Infrared Mapping Spectrometer; R. Carlson, Jet Propulsion Laboratory; surface/atmospheric composition, thermal mapping

Ultraviolet Spectrometer; C. Hord, University of Colorado; atmospheric gases, aerosols

Photopolarimeter Radiometer; J. Hansen, Goddard Institute for Space Studies; atmospheric particles, thermal/reflected radiation

Orbiter (Spinning Spacecraft Section)

Magnetometer; M. Kivelson, University of California at Los Angeles; strength and fluctuations of magnetic fields

Energetic Particles; D. Williams, Johns Hopkins Applied Physics Laboratory; electrons, protons, heavy ions in magnetosphere and interplanetary space

Plasma; L. Frank, University of Iowa; composition, energy, distribution of magnetospheric ions

Plasma Wave; D. Gurnett, University of Iowa, electromagnetic waves and wave-particle interactions

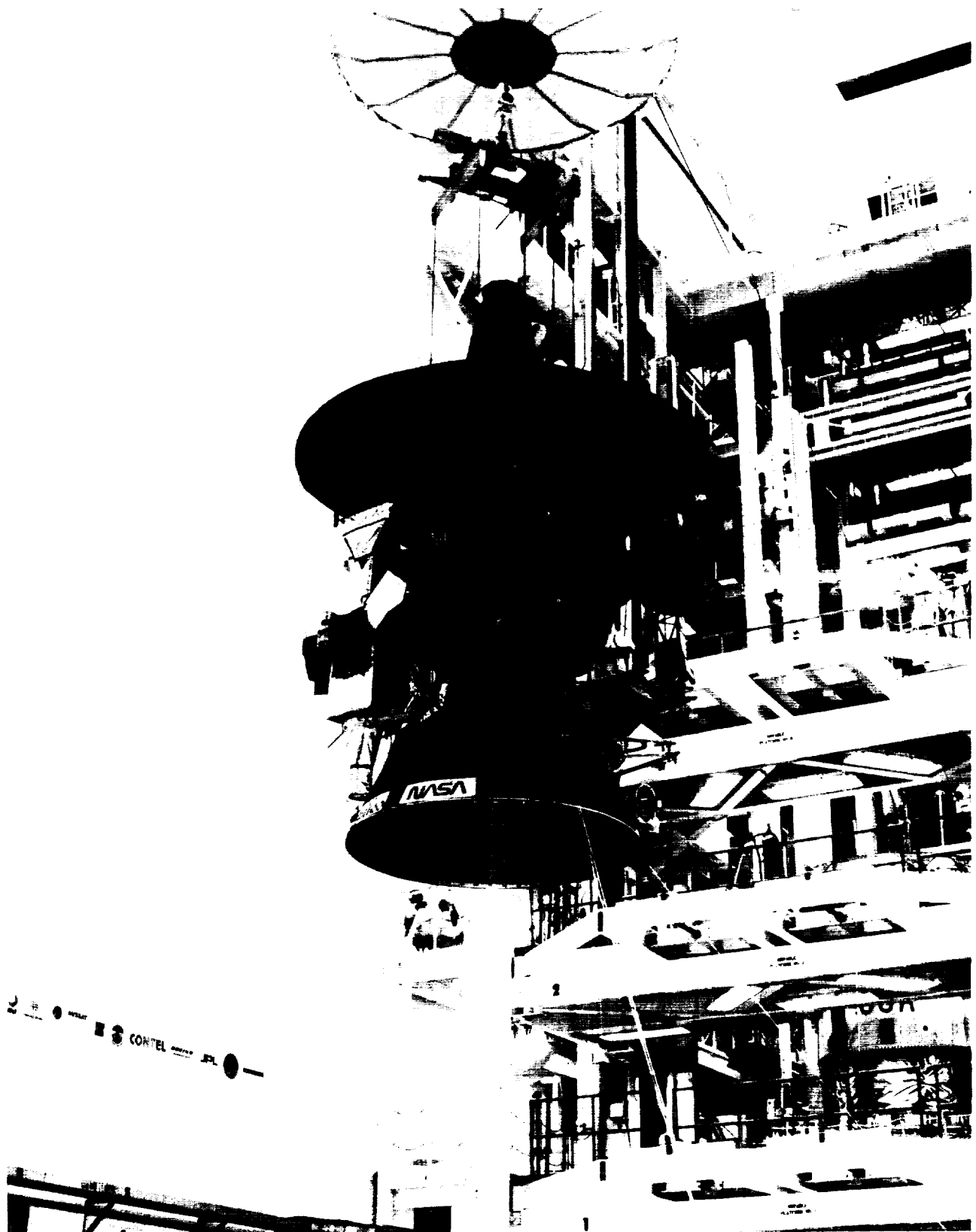
Dust; E. Grun, Max Planck Institute; mass, velocity, charge of submicron particles

Radio Science - Celestial Mechanics; J. Anderson, JPL (Team Leader); masses and motions of bodies from spacecraft tracking

Radio Science - Propagation; H.T. Howard, Stanford University; satellite radii, atmospheric structure

Interdisciplinary Investigators

F. P. Fanale, University of Hawaii; P. Gierasch, Cornell University; D. M. Hunten, University of Arizona; A. P. Ingersoll, California Institute of Technology; H. Masursky, U. S. Geological Survey; D. Morrison, Ames Research Center; M. McElroy, Harvard University; G. S. Orton, NASA Jet Propulsion Laboratory; T. Owen, State University of New York, Stonybrook; J. B. Pollack, NASA Ames Research Center; C. T. Russell, University of California at Los Angeles; C. Sagan, Cornell University; G. Schubert, University of California at Los Angeles; J. Van Allen, University of Iowa



In the Vertical Processing Facility (VPF), Kennedy Space Center, Florida, the Galileo spacecraft is lifted for mating with the Inertial Upper Stage booster in the work stands. Galileo was launched in 1989 and sent toward the planet Jupiter, a journey of more than 6 years. In December 1995 as the 2 $\frac{1}{2}$ ton spacecraft orbits Jupiter with its ten scientific instruments, a probe will be released to parachute into the Jovian atmosphere.

THE COSMIC BACKGROUND EXPLORER (COBE) - Delta

Launch Vehicle - A Delta 5920 expendable launch vehicle provided by McDonnell Douglas, Huntington Beach, California launched the Cosmic Background Explorer. This was the 184th and last NASA-owned Delta launch vehicle.

Program Overview - The Cosmic Background Explorer (COBE) is NASA's spacecraft launched to study the origin and dynamics of the universe, including the theory that the universe began about 15 billion years ago with a cataclysmic explosion—the Big Bang.

Project Objectives - COBE was launched into a circular or sun synchronous orbit, 559 mi (900 km) above Earth. This allows the orbit to change about one degree per day, letting COBE make its full-sky survey.

COBE's objective is to measure the diffuse infrared radiation (cosmic background) that bombards Earth from every directions, so that COBE's instruments can help clarify such matters as the nature of the primeval explosion, which started the expansion of the universe and made it uniform, and the processes leading to the formation of galaxies.

Spacecraft Description - COBE is 19 ft (6 m) long with an open sunshade 13 ft (4 m) in diameter. COBE weighed approximately 5,000 lb (2,268 kg) at the time of launch.

The upper half of the observatory is the instrument module. It contains the three instruments: the Differential Microwave Radiometer (DMR), Far Infrared Absolute Spectrophotometer (FIRAS), and Diffuse Infrared Background Experiment (DIRBE). In addition to the instruments, the instrument module also contains a liquid helium cryostat for the FIRAS and DIRBE instruments and a shield to protect the instruments from illumination by the Sun and Earth. The shield unfolded when COBE reached its orbit.

The lower half of COBE is the spacecraft module. This part of the observatory contains the mechanical support structure, the attitude control system, and the spacecraft and instrument electronics. The attitude control system points COBE in the correct direction and is comprised of Sun and Earth sensors, reaction wheels, electromagnets to provide control torque from Earth's magnetic field, a pair

of large rotating momentum wheels, and a complex set of control electronics.

The electronics in the spacecraft module include a command and data handling system, which decodes the commands received by radio frequency transmission from the ground, collects the data from the instruments and spacecraft and prepares the data for transmission to ground. Communications are handled by a NASA standard five-watt transponder and two antennas. Power for all the electronics is provided by solar cell arrays which were unfolded when COBE reached its orbit.

Spacecraft Payload - COBE carried three instruments: the Differential Microwave Radiometer (DMR), Far Infrared Absolute Spectrophotometer (FIRAS), and Diffuse Infrared Background Experiment (DIRBE).

DMR will determine whether the primeval explosion was equally intense in all directions. To distinguish the emissions of the Milky Way galaxy from the true cosmic background radiation, DMR will measure radiation from space at wavelengths of 3.3 mm (0.12992 in), 5.7 mm (0.22441 in), and 9.6 mm (0.37795 in).

FIRAS, covering wavelengths from 0.1 to 10 mm (0.00039 to 0.39370 in), will survey the sky twice during the year-long mission to determine the spectrum of the cosmic background radiation from the Big Bang. FIRAS' sensitivity will be 100 times greater than that achieved so far by equivalent ground-based and balloon-borne instruments.

DIRBE will search for the diffuse glow of the universe beyond our galaxy in the wavelength range from 1 to 300 micrometers (μm), and will use 10 different wavelength filters. DIRBE will use four different types of detectors.

Project Results - COBE was launched from the Western Test Range at Vandenberg Air Force Base, California, by a Delta 5920 launch vehicle on November 18, 1989 at 9:34 a.m., EST.

COBE was the 65th Explorer mission and has the most sensitive detectors ever flown in a space mission.

Major Participants -

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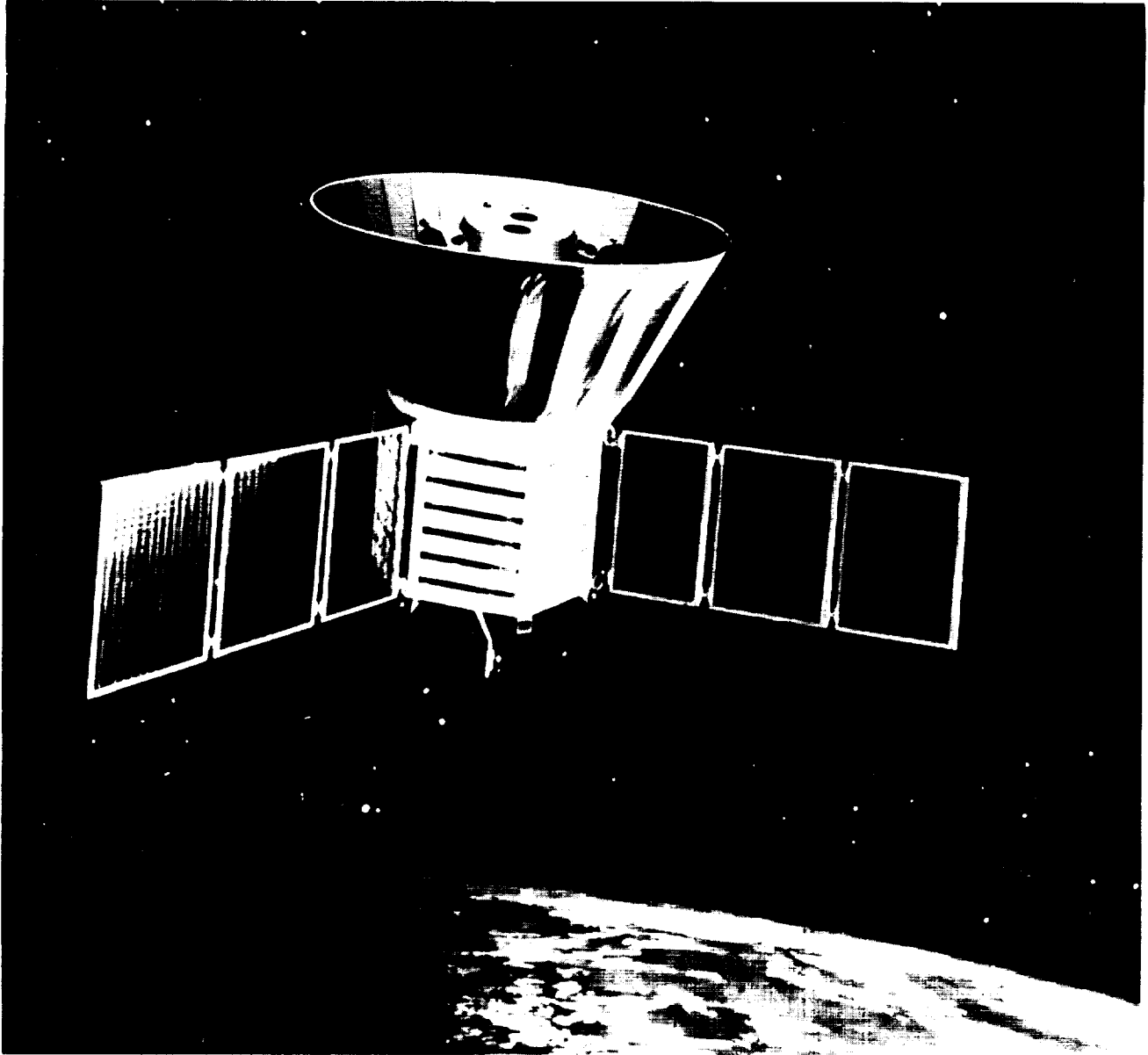
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Kennedy Space Center, Florida

Forrest S. McCartney, Director; John T. Conway, Director, Payload Management and Operations

Contractors

Dr. George F. Smoot, University of California at Berkeley, Principal Investigator for DMR; Dr. Edward L Wright, University of California at Los Angeles, Data Team Leader; L. J. Holloway, Director, McDonnell Douglas Space Systems; McDonnell Douglas Astronautics, Delta Launch Vehicle



The Cosmic Background Explorer (COBE) studies the Big Bang, the primeval explosion that is theorized to have started the expansion of the Universe. It makes a definitive exploration and study of the diffuse radiation of the Universe between the wavelengths of 1 micron and 1 cm (0.393 in). The diffuse universal radiation found in this IR band (specifically the 1- to 300-micron portion), may contain a large portion, if not the dominant part, of the universal energy content, including radiation from primeval galaxies.

